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VEHICLE DETECTOR WITH ENVIRONMENTAL ADAPTATION

BACKGROUND OF THE INVENTION

The present invention relates to vehicle detectors which detect the passage or presence of a

5 vehicle over a defined area of a roadway. In particular, the present invention relates to improved methods of environmental adaption of vehicle detectors.

Inductive sensors are used for a wide variety of detection systems. For example, inductive sensors

10 are used in systems which detect the presence of conductive or ferromagnetic articles within a specified area. Vehicle detectors are a common type of detection system in which inductive sensors are used.

Vehicle detectors are used in traffic control

15 systems to provide input data required by a controller to control signal lights. Vehicle detectors are connected to one or more inductive sensors and operate on the principle of an inductance change caused by the movement of a vehicle in the vicinity of an inductive

20 sensor. The inductive sensor can take a number of different forms, but commonly is a wire loop which is buried in the roadway and which acts as an inductor.

The vehicle detector generally includes circuitry which operates in conjunction with the induc-

25 tive sensor to measure changes in inductance and to provide output signals as a function of those inductance changes. The vehicle detector includes an oscillator circuit which produces an oscillator output signal having a frequency which is dependent on sensor

30 inductance. The sensor inductance is in turn dependent on whether the inductive sensor is loaded by the presence of a vehicle. The sensor is driven as a part of a resonant circuit of the oscillator. The vehicle

detector measures changes in inductance in the sensor by monitoring the frequency of the oscillator output signal.

Examples of vehicle detectors are shown, for example, in U.S. Patent 3,943,339 (Koerner et al.) and in U.S. Patent 3,989,932 (Koerner).

Detection of a vehicle is accomplished by comparing a measured value based on the oscillator frequency to a reference value. The reference value should be equivalent to the measured value when the sensor area is unoccupied. If the vehicle detector has an incorrect reference value, errors in detection may occur. These errors may result in vehicles over the sensor not being detected, vehicles being detected when the sensor area is actually empty, and a single vehicle being detected as multiple vehicles.

Vehicle detectors in use today use relatively blind approaches to adjusting the reference value in an attempt to track oscillator frequency changes caused by the environment rather than by vehicles. The methods of adjusting the reference value utilized in prior art detectors include: adjusting the reference value toward the current measurement value by a fixed amount during each fixed time interval; adjusting the reference value toward the current frequency measurement value by a fraction of the difference between the two during each fixed time interval; adjusting the reference value immediately to the current measurement value if the current frequency decreases for a predetermined amount of time; utilizing an alternative amount of adjustment of the reference value per fixed time interval when a vehicle is over the sensor; and setting the reference value to the current measurement value a fixed amount of

time after the vehicle is no longer detected. Prior art vehicle detectors use various combinations of these approaches. An example of environmental tracking in vehicle detectors is U.S. Patent 4,862,162 (Duley).

5 Each of these approaches results in a high probability that the reference value will be set to the wrong value, particularly during heavy traffic when it is most important that it be set correctly.

SUMMARY OF THE INVENTION

10 The present invention is a combination of methods for adjusting the reference value to compensate for oscillator frequency changes caused by the environment rather than by vehicles. The methods use a check of the vehicle detector reference value

15 immediately following initialization or whenever it is deemed appropriate. This check will be useful, for example, in correcting errors occurring because the detector was initialized with a vehicle over the sensor. The methods also provide for adjustment of the reference

20 value to reflect slow changes in the oscillator frequency caused by the environment. The cause of the changes in the oscillator signal may be identified by using a dummy sensor, which is unaffected by the presence of a vehicle, to determine whether the change

25 is due to temperature or humidity as opposed to environmental changes external to the detector. Additionally, the methods identify changes in oscillator frequency caused by mechanical difficulties which require maintenance activity to correct.

30 ## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of an inductive sensor vehicle detector which is capable of utilizing the environmental adaptation methods.

Figure 2 is a graph illustrating measured period (T) of the oscillator signal as a function of time (t) as a vehicle passes through a detection area associated with the inductive sensor.

5 ## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

(1) General System Description

Vehicle detector 10 shown in Figure 1 is a four channel system which monitors the inductance of inductive sensors 12A, 12B, 12C and 12D. Each inductive

10 sensor 12A-12D is connected to an input circuit 14A-14D, respectively. Sensor drive oscillator 16 is selectively connected through input circuits 14A-14D to one of the inductive sensors 12A-12D to provide a drive current to one of the inductive sensors 12A-12D. The particular

15 inductive sensor 12A-12D which is connected to oscillator 16 is based upon which input circuit 14A-14D receives a sensor select signal from digital processor 20. Sensor drive oscillator 16 produces an oscillator signal having a frequency which is a function of the

20 inductance of the inductive sensors 12A-12D to which it is connected.

As also shown in Figure 1, dummy sensor 12E is provided and is connected to sensor drive oscillator 16 in response to a select signal from digital processor

25 20. Dummy sensor 12E has an inductance which is unaffected by vehicles, and therefore provides an indication of need for adjustment or correction of the values measured by inductive sensors 12A-12D.

The overall operation of vehicle detector 10

30 is controlled by digital processor 20. Crystal oscillator 22 provides a high frequency clock signal for operation of digital processor 20. Power supply 24 provides the necessary voltage levels for operation of

the digital and analog circuitry within the vehicle detector 10.

Digital processor 20 receives inputs from operator interface 26 (through multiplexer 28), and receives control inputs from control input circuits 30A-30D. In a preferred embodiment, control input circuits 30A-30D receive logic signals, and convert those logic signals into input signals for processor 20.

Processor 20 also receives a line frequency reference input signal from line frequency reference input circuit 32. This input signal aids processor 20 in compensating signals from inductive sensors 12A-12D for inductance fluctuations caused by nearby power lines.

Cycle counter 34, crystal oscillator 36, period counter 38, and processor 20 form detector circuitry for detecting the frequency of the oscillator signal. Counters 34 and 38 may be discrete counters (as illustrated in Figure 1) or may be fully or partially incorporated into processor 20.

In a preferred embodiment of the present invention, digital processor 20 includes on-board read only memory (ROM) and random access memory (RAM) storage. In addition, non-volatile memory 40 stores additional data such as operator selected settings which is accessible to processor 20 through multiplexer 28.

Vehicle detector 10 has four output channels, one for each of the four sensors 12A-12D. The first output channel, which is associated with inductive sensor 12A, has a primary output circuit 42A, and an auxiliary output circuit 44A. Similarly, primary output circuit 42B and auxiliary output circuit 44B are associated with inductive sensor 12B and form the second

output channel. The third output channel includes primary output circuit 42C and auxiliary output circuit 44C, which are associated with inductive sensor 12C. The fourth channel includes primary output circuit 42D and auxiliary output circuit 44D, which are associated with inductive sensor 12D.

Processor 20 controls the operation of primary output circuits 42A-42D, and also controls the operation of auxiliary output circuits 44A-44D. The primary output circuits 42A-42D provide an output which is conductive even when vehicle detector 10 has a power failure. The auxiliary output circuits 44A-44D, on the other hand, have outputs which are non-conductive when power to vehicle detector 10 is off.

In operation, processor 20 provides sensor select signals to input circuits 14A-14D to connect sensor drive oscillator 16 to inductive sensors 12A-12D in a time multiplexed fashion. Similarly, a sensor select signal to dummy sensor 12E causes it to be connected to sensor drive oscillator 16. Processor 20 also provides a control input to sensor drive oscillator 16 to select alternate capacitance values used to resonate with the inductive sensor 12A-12D or dummy sensor 12E. When processor 20 selects one of the input circuits 14A-14D or dummy sensor 12E, it also enables cycle counter 34. As sensor drive oscillator 16 is connected to an inductive load (e.g., input circuit 14A and sensor 12A) it begins to oscillate. The oscillator signal is supplied to cycle counter 34, which counts oscillator cycles. After a brief stabilization period for the oscillator signal to stabilize, processor 20 enables period counter 38, which counts in response to

la very high frequency (e.g., 20 MHz) signal from crystal oscillator 36.

When cycle counter 34 reaches a predetermined number (N_{seg}) of oscillator 16 cycles after oscillator
5 stabilization, it provides a control signal to period counter 38, which causes period counter 38 to stop counting. The period count is then representative of the period of the oscillator signal from oscillator 16 during one measurement frame segment. After the
10 completion of each measurement frame segment, processor 20 produces a total measurement frame time duration representative of a predetermined number M of measurement frame segment period counts. The M period counts are taken during the current measurement frame
15 segment and M minus one (e.g., three when M is equal to four) past measurement frame segments for that particular inductive sensor; with the M measurement frame segments together constituting a single measurement frame. Processor 20 compares a "measurement
20 value" (total measurement frame time duration T_{FRAME}) to a "reference value" (reference time duration T_{REF}), calculated with no vehicle near the inductive sensor, and a difference is calculated. A change in the count which exceeds a predetermined threshold, ΔT_{Thresh},
25 indicates the presence of a vehicle near inductive sensor 12A-12D.

(2) Reference Value Initialization Check

In the following discussion, changes in the oscillator signal caused by an inductance change of a
30 sensor 12A-12D will be discussed in terms of period (T) rather than frequency (f). This is simply a matter of convenience for mathematical expression. Frequency is equal to the inverse of period (i.e., $f = 1/T$).

8

Frequency is inversely related to sensor inductance (L) while period is directly related to inductance (i.e., an increase in inductance causes an increase in period).

Vehicle detector 10 receives a user settable sensor entry distance d_{entry}, which represents the distance a vehicle must travel to fully enter the sensor area. In the present embodiment, d_{entry} is assumed to be a constant for vehicles longer than the loop. Figure 2 is a graph of measurement value (period T) as a function of time. Individual measurement values are designated by points 220, 230, 232, 234, 236, 238, 240 and 250. As illustrated in Figure 2, processor 20 monitors the measurement values for a minimum threshold change ΔT_{Thresh} which would indicate the initial presence of a vehicle over the inductive sensor. The required change ΔT_{Thresh} has occurred at point 220. Once a vehicle has been detected, processor 20 determines and stores the change in period ΔT of the sensor drive oscillator signal over each of a plurality of measurement frame segments corresponding to the sensor (12A, 12B, 12C or 12D) over which the vehicle was detected. The period measured during a plurality of measurement frame segments is illustrated by points 230, 232, 234, 236, 238, 240 and 250. Processor 20 also determines and stores a magnitude of change in sensor drive oscillator period ΔT_{MAX} 250 and the time at which it occurs. ΔT_{MAX} has been found to correspond to a reasonable estimate of the inductance change that reflects both the time required for the vehicle to enter the sensor detection area and the presence of the vehicle in the sensor detection area. These measurements are used in detecting vehicle speed.

If the number of measurement frame segments
that occur between the detection of a threshold change
in period ΔT_{Thresh} and the magnitude of change in period
ΔT_{MAX} is equal to a predetermined number, e.g. five or
5   more, then processor 20 makes a speed measurement
calculation. The number five has been chosen to ensure
reasonable accuracy. A number larger than five would
increase detector accuracy. In this embodiment, if the
number of measurement frame segments is less than five,
10 then no speed measurement calculations are performed.

Also as illustrated in Fig. 2, processor 20
next estimates the time rate of period change dT/dt of
the sensor drive oscillator signal by summing the
changes in period ΔT for each measurement frame segment
15 between the detection of ΔT_{Thresh} and ΔT_{MAX}, and dividing
the summation by the total time elapsed during those
measurement frame segments.

Eq. 1

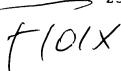$$\frac{dT}{dt} = \frac{\Sigma \Delta T_i}{\Sigma \Delta t_i}$$

20

Processor 20 then calculates the entry time ET for this
particular vehicle, where ET is equal to the maximum
change in period ΔT_{MAX} divided by dT/dt.

25 **Eq. 2**

$$ET = \frac{\Delta T_{MAX}}{\frac{dT}{dt}}$$

Processor 20 next calculates vehicle speed which is equal to the entry distance d_{entry} divided by the vehicle entry time ET.

Eq. 3

$$S = \frac{d_{entry}}{ET}$$

After determining vehicle speed, processor 20 estimates the time, based upon the measured vehicle speed, at which the vehicle will have sufficiently exited the sensor area so as to have substantially no influence on the frequency of the oscillator signal. At the time that was determined to be sufficient for the vehicle to have exited the sensor area, a sample period measurement value T_{SAMPLE} is measured and then compared to the reference value T_{REF}. The following equation illustrates one method of making the comparison and subsequent adjustment of T_{REF}:

Eq. 4

$$T_{SAMPLEAV} = \frac{k * \sum_{i=1}^{N} (T_{SAMPLEi} - T_{REFi})}{N}$$

where,

k	=	a constant
$T_{SAMPLEi}$	=	the ith sample value measured
T_{REFi}	=	the reference period value corresponding to $T_{SAMPLEi}$
$T_{SAMPLEAV}$	=	average difference between T_{SAMPLE} and T_{REF}

$$N = \text{the number of samples taken} = \text{a function of the difference between } T_{SAMPLE} \text{ and } T_{REF}$$

If T_{SAMPLE} minus T_{REF} is greater than a predetermined value P, T_{REF} will be adjusted to equal $T_{SAMPLEAV}$ using N=1 and k≈1. In other words, T_{REF} is set to T_{SAMPLE} in this case.

If the difference between T_{REF} and T_{SAMPLE} is less than P, then detector 10 takes a larger number of additional sample measurements (e.g. N=4), each after a different vehicle is determined to have completed a pass over the sensor area. The additional sample measurements are then compared. If samples are consistent, as defined by a predetermined range, processor 20 calculates $T_{SAMPLEAV}$ according to the above formula. The reference value T_{REF} is then adjusted to equal the average sample value $T_{SAMPLEAV}$.

(3) Identification of Temperature and Humidity Caused Changes in Oscillator Frequency

Processor 20 provides a sensor select signal to dummy sensor 12E, causing it to be connected to sensor drive oscillator 16. The frequency of sensor drive oscillator 16 is then measured while connected to dummy sensor 12E. Processor 20 next compares the measured frequency F_{MDS} (or period T_{MDS}) to a previously measured frequency F_{PDS} (or period T_{PDS}) of dummy sensor 12E.

Since the effects of temperature and humidity on dummy sensor 12E can be measured and calibrated, and since only temperature and humidity may have an affect on the oscillator frequency while connected to dummy sensor 12E, these measurements provide a means for

identifying environmental changes. Changes in temperature and humidity, which affect sensors 12A-12D as well as dummy sensor 12E, will be identifiable and the reference frequency may be adjusted accordingly. If

5   no change in dummy sensor frequency is detected, processor 20 will be able to determine that any environmental effects on the sensor drive oscillator signal while connected to sensors 12A-12D, are due to environmental changes other than temperature and

10   humidity effects on detector components, and therefore are likely external to vehicle detector 10.

       Note that dummy sensor 12E is used as a means of identifying environmental changes which affect oscillator frequency. It is not used directly as a

15   means of adjusting the reference value T_{REF} because external environmental changes may offset the effects of temperature and humidity on detector components.

(4) Identification of Changes in Oscillator Frequency Caused by Mechanical Difficulties or External Interference

20   This method may be utilized to identify changes in sensor drive oscillator frequency caused by mechanical difficulties, rather than by a vehicle or other environmental changes, and which require

25   maintenance activity to permanently eliminate. Vehicle detector 10 measures the frequency change ΔF (or period change ΔT) of the sensor drive oscillator signal over each of a plurality of measurement frame segments. Next, processor 20 measures the rate of change dF/dt (or

30   dT/dt) of the sensor drive oscillator signal by summing the measured changes in frequency ΔF (or period ΔT) for each of the plurality of measurement frame segments, and dividing the summation by the total time elapsed during those measurement periods.

Eq. 5A

$$\frac{dF}{dt} = \frac{\sum \Delta F_i}{\sum \Delta t_i}$$

or

Eq. 5B

$$\frac{dT}{dt} = \frac{\sum \Delta T_i}{\sum \Delta t_i}$$

The rate of frequency change dF/dt or period change dT/dt caused by mechanical difficulties or external interference is normally much greater than the rate of change caused by vehicles or by other environmental changes. In practice, the maximum time rate of change of inductance of a sensor which will be caused by a vehicle is approximately 500nh/millisec. The corresponding maximum dF/dt or dT/dt for a particular vehicle detector will depend on the particular sensor and oscillator circuit used.

Processor 20 monitors the measured rate of change dF/dt (or dT/dt) of the sensor drive oscillator signal for a rate of change greater than a threshold rate of change. Measurement of a rate of change surpassing the threshold rate of change is indicative of mechanical difficulties. Upon measurement of a rate of change indicative of mechanical difficulties, processor 20 takes a predetermined number of sample frequency measurements F_{SAMPLE}. If successive F_{SAMPLE} measurements indicate a permanent change in frequency F after the excessive dF/dt, the detector will reinitialize the

channel and attempt to reestablish T_{REF}.   Processor 20
does, however, record the occurrence as an indication of
mechanical difficulties to unit operators.

(5) <u>Adjustment of Reference For Drift</u>

5   This method may be utilized to adjust the
reference value of a vehicle detector to reflect slow
changes (drift) in oscillator frequency caused by the
environment.   During initialization, processor 20
conservatively calculates a maximum measurement period
10    $T_{measmax}$ which is used to prevent the classification of
anticipated drift as vehicle presence.   This value
$T_{measmax}$ could alternatively be stored as a constant in
the ROM of processor 20.   In this embodiment, $T_{measmax}$ is
calculated as follows:

15   **Eq. 6A**

$$T_{measmax} = \frac{16 * T_{cry}}{(\Delta T_{Sdriftmax} + \Delta T_{Ddriftmax}) * \Delta t}$$

When $\Delta t \approx 4T_{measmax}$ as would be the case in a four
channel detector, Eq. 6A becomes:

                                                                          Eq. 6B

$$T_{measmax} = \sqrt{\frac{16 * T_{cry}}{(\Delta T_{Sdriftmax} + \Delta T_{Ddriftmax}) * 4}}$$

20

where,

Δt =   time   between   successive
measurement starts or stops

T_{cry} =   the   period   of   crystal
25   oscillator 36 which is being
counted   to   measure   sensor
drive oscillator frequency.

/ 5

$\Delta T_{Sdriftmax}$ =   the maximum drift rate expressed as a fraction of sensor drive oscillator period caused by the sensor and other components exterior to the detector.

$\Delta T_{Ddriftmax}$ =   the maximum drift rate expressed as a fraction of sensor drive oscillator period caused by components internal to the detector.

$$If \; \Delta T_{Sdriftmax} + \Delta T_{Ddriftmax} > \frac{10^{-5}}{second}, \; then \; T_{measmax} = 141 \, millisec$$

Use of a dummy sensor allows the direct measurement of actual oscillator drift. This allows longer $T_{measmax}$ values than shown above, because in this case, only external drift rates need to be accommodated, e.g. $\Delta T_{Ddriftmax}$ = 0 may be used in Eqs. 6A or 6B.

During normal operation, detector 10 measures the change in period ΔT of the sensor drive oscillator signal during each successive maximum measurement period $T_{measmax}$. Processor 20 then compares the change in period ΔT, measured during $T_{measmax}$, to a threshold change in period of ΔT_{Thresh}.

If the change in period ΔT over the maximum measurement period $T_{measmax}$ is less then ΔT_{Thresh}, then the reference value T_{REF} is adjusted by adding the change in period ΔT:

$$If \; \Delta T < \Delta T_{Thresh}, \; then \; T_{REF1} = \Delta T + T_{REF}$$

where,

Eq. 7

$$F_{REF1} = \frac{1}{T_{REF}}$$

If the change in period ΔT is greater than ΔT_{Thresh}, the reference frequency is not adjusted.

(6) Conclusion

The present invention makes adjustments to the reference value used in a vehicle detector only when there are indications that a change caused by environmental factors has occurred. Shifts in measured values caused by mechanical problems or by other causes which may not be correctable by a change in reference value are identified.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.